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Polarization Angle Calibration Using the VLA Monitoring Program

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ABSTRACT

We describe our ongoing efforts to monitor the properties of a selected set of calibrators with the VLA at 5, 8, 22 and 43 GHz. We also report on multi-frequency VLBA observations of ~10 sources that assess the efficacy of the EVPA calibration transfer from the VLA to the VLBA. Strategies for fair (±5°) and good (±3°) EVPA calibration using the VLBA are presented.

1. Introduction

The final step in the calibration of polarimetric data is to determine the R-L phase difference of the reference antenna. Ideally this instrumental term would be measured by injecting an artificial signal into the front-end and measuring its propagation through the receiver. The pulse cal tones might provide such a signal, but the stability of the achievable calibration is unknown and beyond the scope of this memo. The R-L phase is directly related to the absolute electric vector position angle (EVPA) on the sky. For tied arrays like the VLA there exist a small number of moderately strong sources with known and constant polarization properties (e.g., 3C286). For the VLA a single 2 minute snapshot observation suffices to determine the observed EVPA, $\chi_{\rm obs}$, and the necessary correction is just that needed to rotate $\chi_{\rm obs}$ to the known angle (33° for 3C286).

For VLBI observations, however, there are no strong compact sources in the sky with known polarization properties. The cores and jets of AGN may be polarized at levels up to 20%, but the emission regions are necessarily compact, and can vary on timescales from months to hours. Sources with known and constant polarization properties like 3C286 resolve out for the VLBA at wavelengths shorter than about 6cm. For some time it was hoped that the strong, long-lasting jet components of a few sources, (e.g., 3C279) would be stable on timescales of years (Taylor 1998), but recent observations have revealed that the EVPA of even these long-lived jet components swing gently (~5°) on timescales of months (R. Mutel, private communication; Zavala & Taylor 2000).

While such sources may still be extremely useful in checking on and refining the EVPA calibration (see §4), they cannot be used as the sole reference for an observing run.

The method most practiced over the years to calibrate the EVPA for VLBI observations is to observe a compact, polarized source quasi-simultaneously with both the VLA and VLBA arrays at the same frequency. The VLA obervation can be calibrated in the usual way, with EVPA determined by an observation of 3C286, and thus the polarization properties of the compact source at this epoch are known. Assuming that the VLBA sees the same emission as the VLA then the absolute EVPA can be set using this compact source. With many polarimetric observations taking place at the VLA each month, it becomes difficult and inefficient to schedule the necessary VLA observations for every VLBA observer.

In §2 we report on a monitoring program with the VLA to provide the measurements needed to calibrate the EVPA at the VLBA. This technique is put to the test in §3, and a proposed strategy for obtaining highly accurate EVPA calibration is put forth in §4. In §5 we summarize potential uses of the VLA monitoring program.

2. The VLA Monitoring Program

What is desired for the VLA monitoring program is to provide regular observations of a set of sources, widely distributed in Right Ascension, that are compact, yet stable enough in their polarization properties that it is possible to interpolate between measurements. The sources chosen need to be strong enough in total intensity, S, and linearly polarized intensity p, that they can be imaged, and provide a good measure of the polarization angle, χ, with good SNR in 2 or 3 snapshots of $\sim$4 minutes each at a given frequency.

The monitoring program began in September 1999 at monthly intervals and for the bands C, X, K and Q (5, 8, 22 and 43 GHz). It was decided not to provide data at L band because 3C286 and 3C138 are available for calibration of that band. The U band (15 GHz) was left out due to time pressures with the expectation that it would generally be possible to interpolate the EVPA measured between 8 and 22 GHz. Even in its early stages it was recognized that the greatest challenge would be to find strongly polarized ($p > 30$ mJy, $m > 1\%$), and stable calibrators at the high frequencies.

We began by selecting sources from the 2cm survey of Kellermann *et al.* (1998). We also selected sources that were rumored to be bright and strongly polarized at high frequencies (A. Kemball, private communication).

Each epoch of the VLA monitoring program is typically 2–3 hours long. An observation of 3C286, 3C138 or 3C48 is used to set the absolute flux and EVPA calibration. A strong point source near 30 degrees declination is observed 4–5 times in order to solve for the polarization leakage terms. The time remaining allows for about 5 sources from the monitoring program to be observed.

Reference pointing at X-band is carried out for the 22 and 43 GHz observations for each target. The data are manually editted and then fed into an automatic reduction script. These scripts are available from the VLA/VLBA calibration page (http://www.aoc.nrao.edu/~smyers/calibration/), as are the gain curves used in the calibration. The results of the script are a Stokes I flux density, linearly polarized flux density, fractional linear polarization and polarization angle. These results are tabulated and plotted in the Master Calibration Database at the above URL.

Beginning in April, 2000 the monitoring interval was increased to twice monthly due to the rapid variations seen in the EVPA of many of the calibrator sources at high frequencies (e.g., Fig. 1). A more usable calibrator is shown in Fig. 2.

3. VLBA test results

For the tie from the VLBA to the VLA to work it is essential that the source observed not have a large amount of polarized emission on scales larger than the VLBA can image. Such emission could influence the VLA measurement without being visible to the VLBA. The simplest policy might be to require the sources to be unresolved to both instruments, yet that selection could result in picking only highly variable sources which are also undesirable. In practice it is necessary to combine the VLA monitoring observations with VLBA observations of several calibrators in order to image the pc-scale structure and see how well the calibrators agree.

We observed ~10 candidate EVPA calibrators from the VLA monitoring program at C, X, K and Q bands with the VLBA on 1999 Nov.12 and 1999 Nov.18. Each source was observed for 2×5 minutes at each frequency. The reference antenna used for fringe fitting and polarization calibration was FD. At C band almost all sources could be imaged, but 3C84 had no detectable polarized emission. At the higher frequencies some of the selected sources were too weak to image and/or had no detectable polarized emission. Both the VLA and VLBA results for the sources are tabulated in Tables 1–4. The VLA results are nearby in time, or interpolated from the monitoring program. The VLBA results (S_Q, S_U, etc.) are integrated quantities summed over the source. The EVPA calibration (R-L difference in degrees of the reference antenna – see Tables) derived from each source is shown in Fig. 3. The rms variation in the corrections at C and X band is less than 6 degrees. At K and Q bands the spreads are 17 and 13 degrees respectively. This increased error is primarily due to the increase in variability of the sources at the higher frequencies which are dominated by more compact emission regions. No detectable variation in the R-L phase of the reference antenna between the two runs was seen at any band. The final, fully-calibrated polarization images at all bands are shown in Fig. 4 for J1310+3220. The complete set of calibrated images can be found at the web page (http://www.aoc.nrao.edu/~smyers/calibration/). Based in part on the analysis presented here, we have refined our list of calibrators to concentrate in the future on those sources that have shown the best stability in polarization properties at K and Q bands. Another round of VLBA observations will take place in late 2000 to verify the applicability of these most stable calibrators.

4. Strategies for EVPA Calibration on the VLBA

Passable EVPA calibration (good to ±5 degrees) at C or X band can be readily achieved by observing 2 calibrators from the VLA monitoring page for 2 × 5 minutes at each frequency of interest. Observing additional calibrators will improve the estimate and guard against a misbehaving (e.g., flaring) EVPA calibrator. At the higher frequencies, the calibrators should be chosen with somewhat greater care, paying close attention to recent trends shown in the VLA monitoring. If the polarized flux density of the EVPA calibrator is weak (10–20 mJy) then it may be necessary to get 4 × 5 minutes at each frequency of interest. Note that any calibrator polarized less than 0.5% should be avoided. Some of the best behaved sources at high frequencies at the time this goes to press (Oct. 2000) are J0423-0120, J0854+2006, J1310+3220, J1751+0939, and J2136+0041.

If a more accurate EVPA calibration is needed then it may be achieved by performing multi-frequency observations of 3C279 or J2136+0041 in addition to 2–3 calibrators from the VLA monitoring program. The jet component, C4, in 3C279 is particularly strong and relatively stable in both EVPA and RM. The strongly polarized jet component can be used to correct out small differences between IFs and multi-frequency observations can identify systematic EVPA calibration errors at a given frequency. An example application of this technique by Zavala & Taylor (2000) is shown graphically in Figure 5. The cost of this method can be quite high since leakage terms need to be solved for at each frequency of interest. Generally this can be accomplished by observing 3C279 over a range in parallactic angle, but even so this can require as much as half the available time being spent on calibration. The properties of the jet components of 3C279 and J2136+0041 are summarized for both sources in Table 5.

5. Summary of Potential Uses

While this program was established to provide a mechanism for absolute EVPA calibration of the VLBA, there are a number of other uses for the data collected here. These include:

(1) EVPA calibration for the VLA during short observations around LST 20^h when it is not possible to reach 3C286 or 3C138.

(2) EVPA calibration of other instruments.

(3) Absolute flux calibration of the VLBA. At C and X band the flux densities from the automatic reduction are accurate to ~5%. At higher frequencies the accuracy is considerably degraded (~10–20%) due to poor assumptions about the atmospheric opacity, antenna gain curves, and pointing errors. This method may not provide a better calibration than the standard *apriori* gain calibration derived from system temperatures, but it can provide a useful check.

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REFERENCES

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TABLE 1

C BAND (5 GHz) RESULTS

Source	$S_{\rm VLA}$ (mJy)	$P_{\rm VLA}$ (mJy)	$\chi_{\rm VLA}$ (deg)	$S_{\rm VLBA}$ (mJy)	S_Q (mJy)	S_U (mJy)	$P_{\rm VLBA}$ (mJy)	$\chi_{\rm VLBA}$ (deg)	R-L (deg)	$\chi_{\rm cor}$ (deg)
TP16A – 1999 Nov. 18										
DA193	6195	45	−39	6449	67	1.3	67	0	39	−43
BLLAC	3254	120	8	3110	−15.0	109	110	49	41	6
J0238+1636	1760	24	−5	1777	0.2	18.8	19	45	50	2
J1635+3808	2482	22	15	2360	−6.5	20.9	22	54	39	11
J1638+5720	1217	18	−40	1236	13.0	3.9	14	8	48	−35
J1743−0350	4655	73	−12	5092	80.4	90.5	121	24	36	−19
J1751+0939	2506	151	−2	2623	30.9	176.0	179	40	42	−3
TP16B – 1999 Nov. 12										
3C84	20637	6	25	20458	41	58	71	−64	91	N/A
DA193	6195	45	−39	6634	47	12	49	7	46	−36
3C286	7486	834	33	2219	−275	25	276	87	54	11
J0609−1542	7811	47	22	5855	−17	20	26	65	43i	22
J0927+3902	10686	80	22	11067	−59	73	94	64	41	21
J1310+3220	1853	41	−7	1930	16	39	44	34	41	−9

TABLE 2

X BAND (8.4 GHz) RESULTS

Source	$S_{\rm VLA}$ (mJy)	$P_{\rm VLA}$ (mJy)	$\chi_{\rm VLA}$ (deg)	$S_{\rm VLBA}$ (mJy)	S_Q (mJy)	S_U (mJy)	$P_{\rm VLBA}$ (mJy)	$\chi_{\rm VLBA}$ (deg)	R-L (deg)	$\chi_{\rm cor}$ (deg)
TP16A – 1999 Nov. 18										
DA193	6190	51	−64	5807	−53.3	110	122	58	72	97
BLLAC	3396	113	40	3611	129	−2.4	129	−1	−41	38
J0238+1636	2178	37	−7	1942	0.0	−31	31	45	52	84
J1743−0350	4400	100	−28	3954	−83	−65	105	−71	−43	−32
J1751+0939	2871	225	−22	2592	−106	−179	208	−60	−38	−21
TP16B – 1999 Nov. 12										
3C84	20190	20	30	20024	27	33	43	N/A	N/A	N/A
DA193	6190	51	−64	6430	−47	17	50	80	−36	−61
J0609−1542	9000	150	0	8054	43	−163	168	−38	−38	1
J0927+3902	11993	87	15	12420	43	−52	67	−25	−40	14
J1310+3220	1730	45	−10	1746	−19	−43	48	−57	−47	−18

TABLE 3

K BAND (22 GHz) RESULTS

Source	S_{VLA} (mJy)	P_{VLA} (mJy)	χ_{VLA} (deg)	S_{VLBA} (mJy)	S_Q (mJy)	S_U (mJy)	P_{VLBA} (mJy)	χ_{VLBA} (deg)	R-L (deg)	χ_{cor} (deg)
TP16A - 1999 Nov. 18										
DA193	4582	7	−76	3552	32.3	0.2	32	45	−59	−25
BLLAC	4247	147	55	3816	13.2	−147	148	−43	−98	67
J0238+1636	2610	82	13	2218	−11.0	−8.3	14	−71	−84	39
J1743-0350	3888	73	−8	2860	−20.7	38.6	44	59	−113	−11
J1751+0939	3136	295	−35	2137	34.6	201	203	40	−105	−30
TP16B - 1999 Nov. 12										
3C84	14717	110	−75	7406	6	−51	51	−42	−147	68
DA193	4578	7	−76	3677	11	−29	31	−35	−139	75
J0609-1542	13000	200	0	8950	−121	273	298	57	-123	−13
J0927+3902	9400	130	−60	9313	63	−132	146	−32	−150	78
J1310+3220	1300	50	−24	962	−4	39	39	48	−108	−22

TABLE 4

Q BAND (43 GHz) RESULTS

Source	S_{VLA} (mJy)	P_{VLA} (mJy)	χ_{VLA} (deg)	S_{VLBA} (mJy)	S_Q (mJy)	S_U (mJy)	P_{VLBA} (mJy)	χ_{VLBA} (deg)	R-L (deg)	χ_{cor} (deg)
TP16A - 1999 Nov. 18										
DA193	3374	15	67	1681	−12	10	16	70	3	−51
BLLAC	3808	156	52	3086	67	−37	76	−14	−66	45
J0238+1636	2170	39	55	1574	0.5	−0.1	<1	N/A	N/A	
J1743-0350	2400	100	−30	1533	−22	−9	24	−79	−49	−20
J1751+0939	1969	168	−26	1425	−123	8	124	88	−66	−33
TP16B - 1999 Nov. 12										
3C84	8043	43	−72	3513	44	63	77	28	−80	87
DA193	3374	15	67	1856	19	14	24	18	−43	77
J0609-1542	10000	355	87	5966	−105	−100	145	−68	25	−9
J0927+3902	8000	70	−78	5164	35	144	148	38	−64	97
J1310+3220	1000	58	−27	576	−21	−13	25	−74	−47	−15

TABLE 5

3C279 and J2136+0041 RESULTS

Band	$S_{\rm ref}$ (mJy)	$P_{\rm ref}$ (mJy)	$\chi_{\rm ref}$ (deg)	$S_{\rm VLBA}$ (mJy)	$P_{\rm VLBA}$ (mJy)	$\chi_{\rm VLBA}$ (deg)	$\chi_{\rm cor}$ (deg)
3C279-C4	Taylor 1998						
5 GHz	N/A	N/A	90	4057	413	−39	−82
8 GHz	2500	254	70	2962	366	58	−83
22 GHz	N/A	N/A	72	1090	131	−8	−78
43 GHz	N/A	N/A	72	286	52	59	−62
J2136+0041-W	Taylor 2000						
5 GHz	N/A	N/A	N/A	9981	54.6	−81	−28
8 GHz	3810	103	24	3406	116	−3	36
22 GHz	N/A	N/A	−3	700	40	−89	21
43 GHz	N/A						

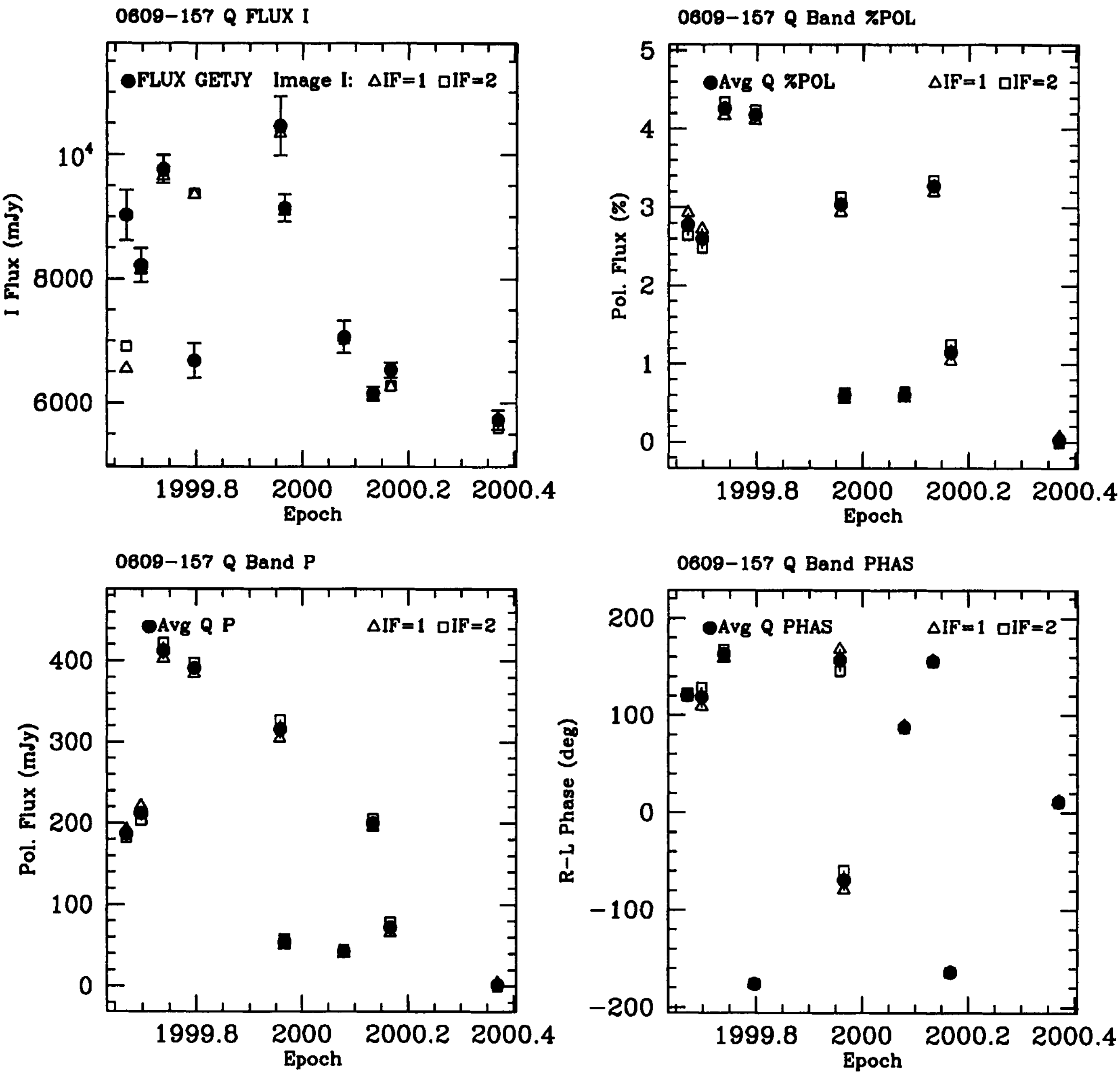

Fig. 1.— An example of the 43 GHz (Q band) results from the strong, but highly variable source J0609−1542. The plot in the **upper left** shows the variation in total intensity as derived from GETJY solutions (circles with error bars) and by measuring the peak in the image at each IF (open triangles and squares). The plot in the **bottom left** shows the variation in polarized flux density for each IF. The plot in the **top right** shows the variation in fractional polarization for each IF. The plot in the **bottom right** shows the EVPA for each IF. This montage illustrates how even sampling the source properties every 2 weeks is still insufficient for this source/frequency combination to allow a reliable calibration transfer.

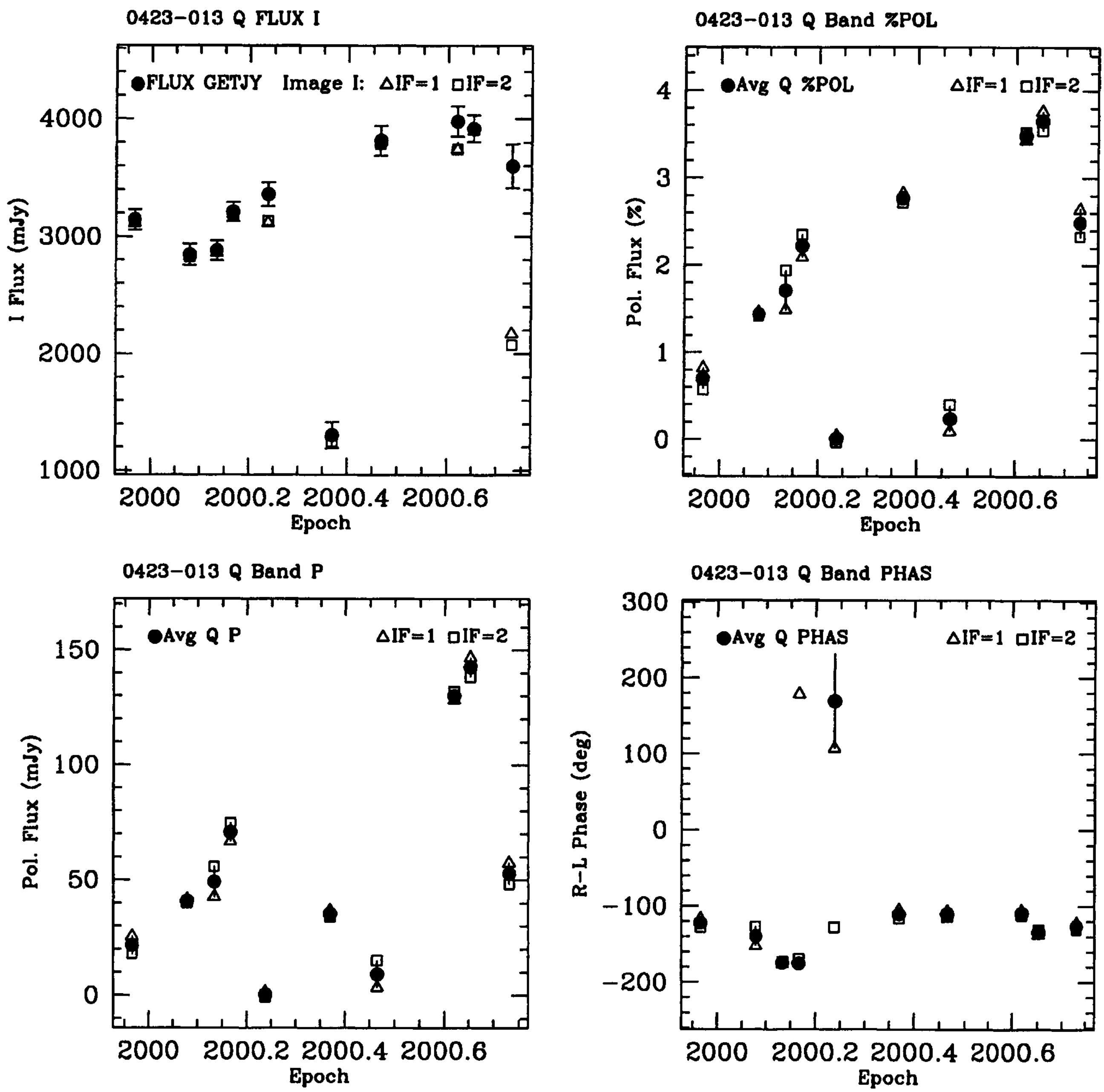

Fig. 2.— An example of the 43 GHz results from the weaker but less variable source J0423-013. It should be possible to interpolate between measurements to form a good calibration transfer.

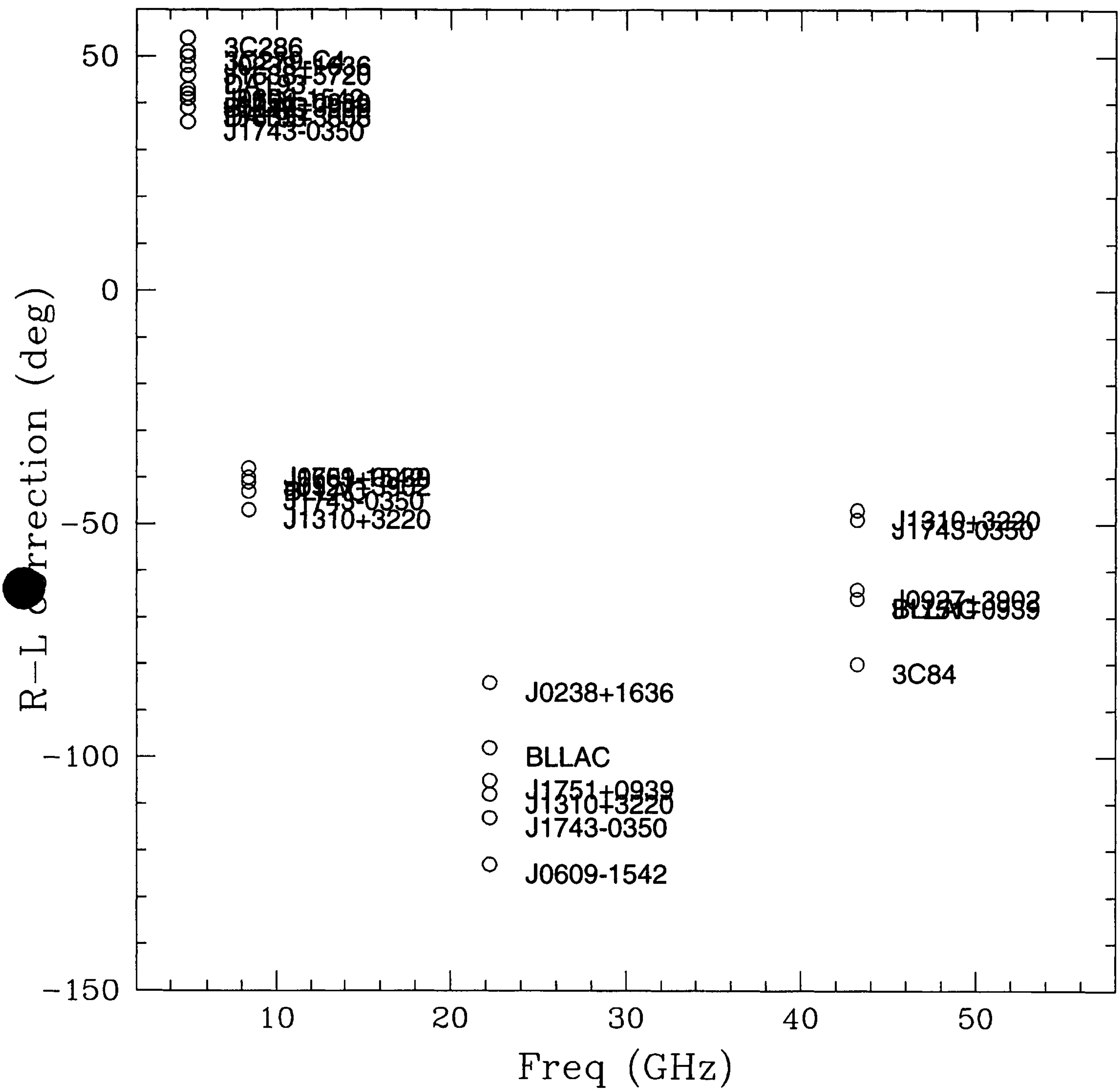

Fig. 3.— The derived R-L phase corrections (in degrees) for the reference antenna (FD) determined independently with several calibrators at each frequency on both Nov. 12 and 18.

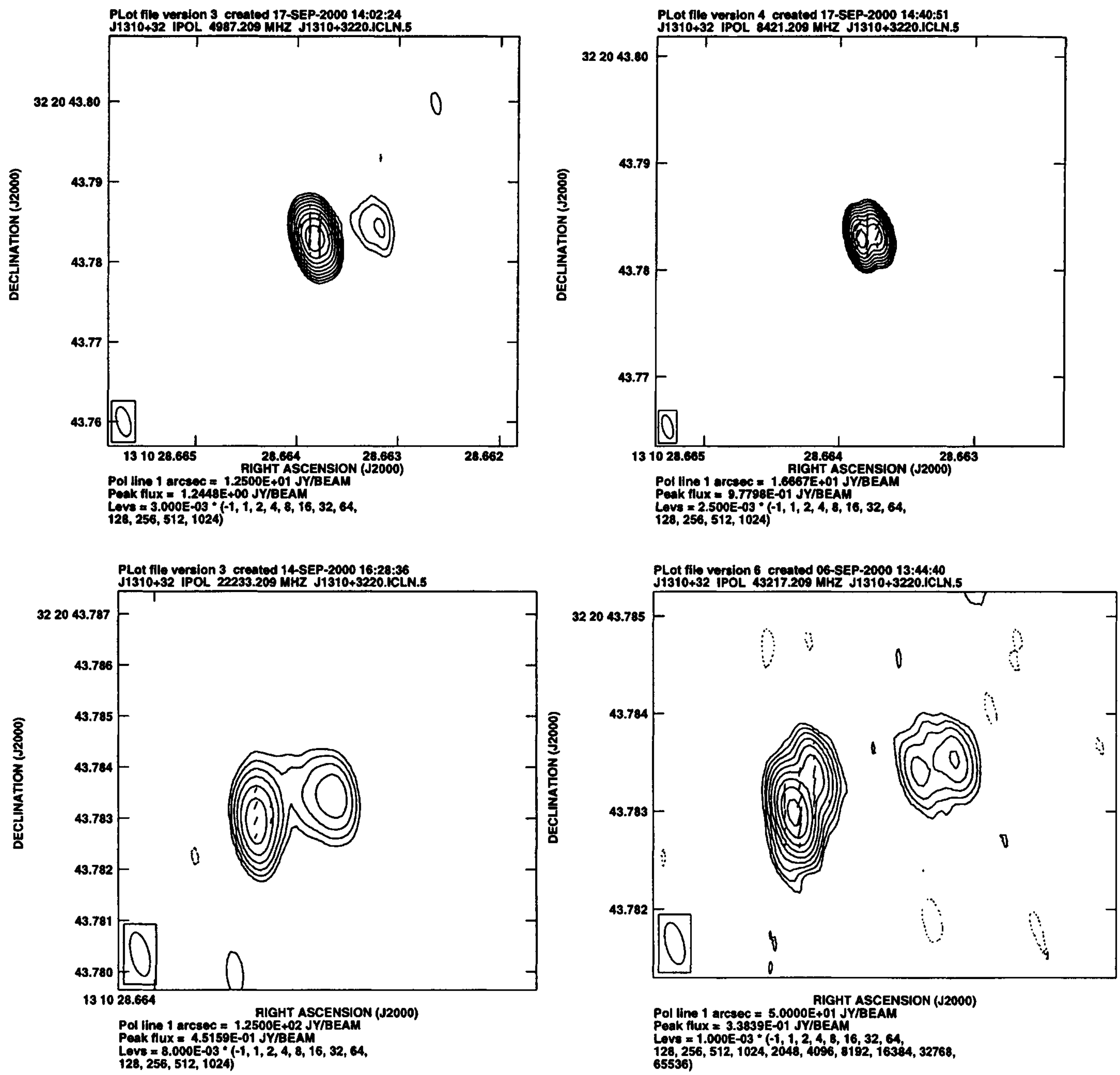

Fig. 4.— Calibrated VLBA images of J1310+3220 at 5–43 GHz. The contours show total intensity starting at ~0.5 mJy/beam and increasing by factor 2 intervals. The polarization vectors are E-vectors, not corrected for any possible Faraday Rotation Measures.

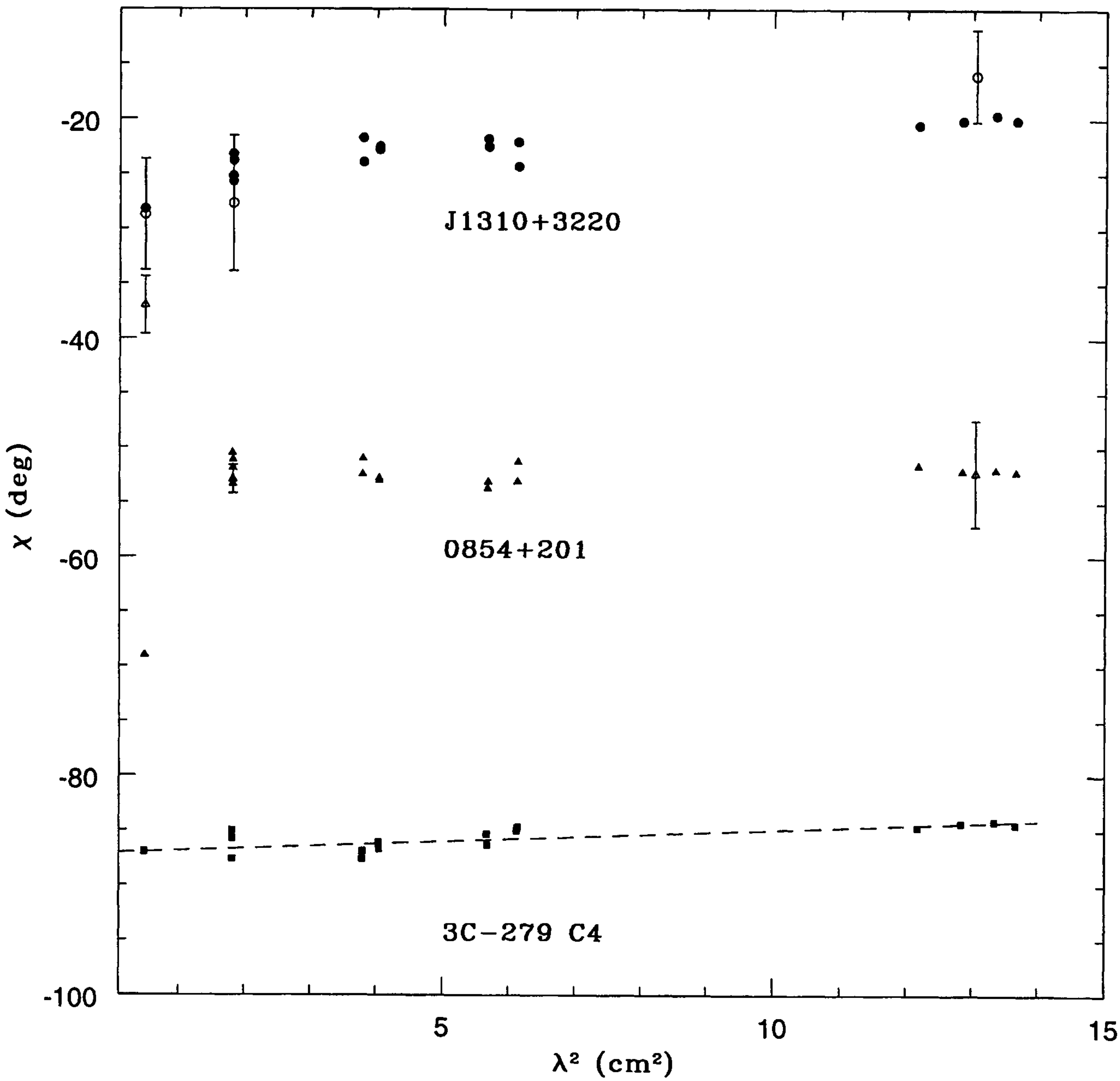

Fig. 5.— This plot is taken from multi-frequency observations by Zavala & Taylor (2000). The EVPA of J1310+3220 (open circles=VLA, filled circles=VLBA), 0854+201=OJ287 (open triangles=VLA, filled triangles=VLBA), and 3C279 C4 (squares) are plotted after applying the average R-L phase correction derived from VLA monitoring observations of OJ287 at 8 and 22 GHz. The 43 GHz calibration was set with 3C279 C4 since the SNR on both J1310+3220 and 0854+201 was low.